Framework for requirement analysis in the design of collaborative robots on construction sides

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Abstract. The workplaces on construction sites are comparatively little automated, as they have a high degree of flexibility in tasks and a diverse physical environment, that makes a high level of automation difficult. However, the physical workload is often very high for construction workers, leading to a high risk for musculoskeletal disorders. It would therefore be conceivable to use physical assistance systems to reduce the workload of the construction worker. This might be achieved by collaborative robots: they can combine the advantages of a robot with those of humans to adapt to different situations.
The following article develops a framework for the requirements that are necessary in order to design a collaborative robot for the work on construction sites. For this engineering and ergonomic approaches are combined. Based on a work system approach and requirements examined for fixed work cells in the industry, the characteristics of the work on a construction site are clustered to. That can be used to derive requirements for the assistive robot.

Keywords: Construction work, human robot collaboration, work system analysis, requirements

1 Introduction

Most construction workers work on their jobs and tasks decentral on their sides under all weather conditions. Therefore, the workplace of the construction worker is regularly changing, when a new project starts. Also building itself contains the remodeling of the environment. This requires a high flexibility and adaption to the physical environment in which the tasks are carried out. Furthermore, one worker often performs a variety of tasks with different demands within their jobs [1]. Compared to automated systems, humans excel in mobility and adaption to new spaces and tasks [2–4] This is the reason why, in most cases, the work on construction sides has a low level of automatisation. However, the risk for musculo-skeletal disorders due to physical workload is high for construction workers. For example, musculo-skeletal disorders caused 20,1 % of the work incapability days in 2016 [2]. Following the TOP principle, usually applied in ergonomics [5], technical solutions should be used first of all to reduce the physiological strain on these workstations.

One possible technical solution is the use of collaborative robots for tasks with high physical demands. A collaborative robot can be defined as a robot that works in close proximity with the work person in the same workspace and is closely interacting with the work person in order to achieve their common work goal [6]. As collaborative robots might be able to work closely together with the human, they combine high repetition accuracy and high physical action force with the benefits of the human worker. Therefore, collaborative robots have been widely advertised as assistive systems adaptable to the work persons needs in industries [4].

This contribution aims to develop a framework for the analysis of user requirements for collaborative robots on construction sides. The framework should help to analyze the special circumstances, on construction sides and due to the near collaboration of human and robot.

2 Method

A multidisciplinary approach is used, combining engineering and ergonomic knowledge, to set the framework. First common methods and procedures in product development process from an engineering and an ergonomic point of view are reviewed. Afterwards general frameworks for requirement analysis are introduced. Then application of these methods in the field of human robot collaboration regarding task allocation and requirement analysis is reviewed.
Based on these insights, a framework for the development of the requirement analyze is derived. To identify the context of use, the work system approach has been used.
Key groups that are derived from the reviewed literature, that consider topics that need to be addressed when designing a robot for a job on a construction side.

3 State of the Art

There is a wide range of methods and approaches that are proposed for product development process they differ in the specific problems that need to be considered the design. Different standard approaches are used for the design of human robot collaboration. While Ore et al. [7] and Duffy et al. [8] adapt the generally known product design process from Pahl and Beitz [9], Nelles et al [10] choose the framework of the human centered design process. Both Ogorodnikova et al. [11] and Weber et al. [4] presents a framework for the development of the work station with high focus on safe physical interaction.

The requirement analysis is a crucial part of all product design processes [9]. In the user centered design process, the requirements are derived from the context of use [12]. The standard proposes to derive them form the context of use, the needs of the user, existing standards, and usability requirements, and organizational requirements.

With focus of the practical implementation, the analysis of potential of industrial human robot collaboration various authors propose both ecological and ergonomic point of views [4, 7–9, 13, 14]. Also the operator participation from an early stage on is considered essential for a successful implementation [4, 15].

Two methods have been found in the literature for application of specific requirements. Ore et al [7] addresses the functional characteristic, quality criteria and geometrical characteristics in the first stage of the design of a human robot workstation. Also the necessity for a rough analysis of the potential form an ecological point of view is highlighted. Weber et al on the contrary focus highly on the safety of the workperson and address technological, medical and biomechanical requirements, ergonomic requirements and work organizational requirements that apply to the safety and wellbeing of the human worker [4, 7, 16, 17]

Both authors focus on safety of the working person as crucial requirement for the successful implementation. To achieve this, the application of applicate the standards EN ISO 10218 part 1 and part 2 defining the safety of industrial robots and the technical specification ISO/TS 150066 for collaborative robots is necessary [4, 14].

Apart from its potential for reducing the physical load, simply introducing a collaborative robot to a work system to take over some or all of the humans physical tasks, is not sufficient enough, to harvest the full potential of the synergies between human and robot [17]. Therefore, task allocation is one of the most important parts on the early development stages for a successful assistive robot [18]. The human performance is highly dependent on the workload, hence, if humans are supervisors without participation, their performance is poor [19]. Therefore, the workload, skills, aptitude and strain of the human needs consideration [4]. There is a wide research body on the strain that might be caused by the robot properties, for example the robots movement and position [20]. An Overview on the impact of robots on the human well-being is provided by Nelles et al [21].

However, these approaches focus on fixed workstations in production lines and cyclic tasks with limited tools and materials. Up to the authors knowledge, there has been no framework of requirements analysis for robots in mobile workplaces or frequently changing tasks. However, this mobility and flexibility needs to be addressed in order to implement a successful and accepted robot on construction sides.

4 Framework

The key objective of the framework is to help implementing human factors, into the technical design process in order to achieve a work system that enables human and robot work together effectively and efficiently on their tasks and to enhance the satisfaction and wellbeing of the human.

Therefore, the first step is to analyze the tasks that need to be fulfilled, the active elements of the work system, its purpose and the input and output of the system. Here there should be especially a focus on the stress that might be caused by the demands of the tasks and the strain and aptitude of the user.

The tasks need to be allocated between robot and working person. As mentioned above, this is takes careful considerations. However, task allocation will be not addressed in this paper.

The requirements that can be analyzed based on the work system are clustered in four groups: functional requirements and user related requirements, the physical environment and organization set requirements. The groups are displayed in Fig. 1. Safety needs to be addressed as foundation for a successful implementation and is related to all groups.

The user related requirements address the overall goal that the human should be able to work along the robot without restriction of his physical and mental well-being Therefore the demands of the working persons remaining tasks should be balanced and the impact of the robot on the strain and aptitude of the worker minimalized. In collaboration, the worker and the robot need to coordinate each other. Therefore, means of communication are necessary. These should have a high usability, especially regarding reprogramming and general control. It is important that there is no reduction of comfort or productivity if the worker is to accept the robot as an assistance system.

Physical environment	Functional requirements	User-related requirements	Organisation
Adaption to changes	Task allocation	Tasks demands	process related requirements
Properties of the environment	Material handling material manipulation	Physical and psychological strain Aptitude and fatigue	economical aspects
	Mobility	User interface Usability	Process planning
	Perception and Processing of the environment		

Fig. 1. Framework of topic groups for the Requirement analysis.

The functional requirements examine from a technical point of view the characteristics and the requirements of the robot directly related to his function. These include requirements that concern the handling of the materials as well as requirements which define the tools the manipulator needs to fulfill the tasks. On construction sides, the variety of jobs and their tasks need to be accessed. Also the materials that are often viscous can be challenging for the manipulator. In many cases it might be suitable to have a mobile solution, that can move independently within the work space. For this and also for safety, the robot's perception and information processing capabilities need to be dimensioned appropriately.

This leads to the third group the physical environment. As mentioned above, the construction sides are often distributed decentral. So the robot needs to be able to adapt to new environments. Also, the workspace is constantly changing, which is challenging the robot. The types of different situations need to be considered. The properties of physical environment also can be confounding factors- on construction sides there is often humility, dirt or dust, that can affect the system heavily. The robot should be design resilient against these.

The fourth group is summarizing the demands that arise regarding output of the work system and the overall planning. These concern the overall system efficiency, economical aspects, such as the price of the robot and the criteria for evaluation regarding to the standards.

5 Conclusion

With this framework the requirements for the robot as assistance and support system on a construction site can be examined. With the work system approach it is assured, that all aspects of the future workplace are considered. In future, the framework will be applied and evaluated on the example of tilers. Furthermore, more research should be carried out on the topic of task allocation in non -cyclic tasks and the impact of the robot on the strain and aptitude of the work person.

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